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A Comparison of Earned Value and Earned Schedule Duration Forecast Methods on Department of Defense Major Defense Acquisition Programs

Bruchey, William J.

Monterey, California. Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

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A Comparison of Earned Value and Earned Schedule Duration Forecast Methods on Department of Defense Major Defense Acquisition Programs

By: William J. Bruchey
September 2012

Advisors: Charles Pickar
William Fast

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Earned schedule uses standard earned value management performance indicator values and time-based equations to depict the schedule performance.

This research project measured the accuracy of earned value and earned schedule final duration forecast methods by analyzing four U.S. Army Chemical Materials Agency programs.

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A COMPARISON OF EARNED VALUE AND EARNED SCHEDULE DURATION FORECAST METHODS ON DEPARTMENT OF DEFENSE MAJOR DEFENSE ACQUISITION PROGRAMS

William J. Bruchey
Civilian, United States Army
B.S., Mechanical Engineering, Clemson University, 1991

Submitted in partial fulfillment of the requirements for the degree of

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from the

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September 2012

Authors: ______________________________
William J. Bruchey

Approved by: ______________________________
Charles Pickar, Lead Advisor

____
William Fast, Support Advisor

____
William Gates, Dean
Graduate School of Business and Public Policy

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LIST OF ACRONYMS AND ABBREVIATIONS

ACWP	Actual Cost of Work Performed
ANSI	American National Standards Institute
AT	Actual Time
AT&L	Acquisition, Technology & Logistics
ATE	Actual Time Expended
BAC	Budget at Completion
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
$BCWS_{av}$	Average Budgeted Cost of Work Scheduled
$BCWS_{cum}$	Cumulative Budgeted Cost of Work Scheduled
CMA	Chemical Materials Agency
CPM	Critical Path Method
CPR	Contract Performance Report
C/SCSC	Cost/Schedule Control Systems Criteria
DFARS	Defense Federal Acquisition Regulation Supplement
DID	Data Item Description
DoD	Department of Defense
DoDI	Department of Defense Instruction
EIA	Electronic Industries Alliance
ES	Earned Schedule
EV	Earned Value
EV_{av}	Average Earned Value
EV_{cum}	Cumulative Earned Value
EVM	Earned Value Management
EVMIG	Earned Value Management Implementation Guide
EVMS	Earned Value Management Systems
FD	Actual Final Duration
IEAC(t)	Independent Estimate at Completion
$IEAC(t)_{BCWS}$	Independent Estimate at Completion–BCWS method
$IEAC(t)_{ES}$	Independent Estimate at Completion–ES method

$IEAC(t)_{EV}$	Independent Estimate at Completion–EV method
IMS	Integrated Master Schedule
MDAPs	Major Defense Acquisition Programs
MSE	Mean Squared Error
PD	Planned Duration
PMB	Performance Measurement Baseline
PV	Planned Value
RMSD	Root Mean Square Deviation
SPI	EVM Schedule Performance Index
SPI(t)	ES Schedule Performance Index
USD	Under Secretary of Defense
WBS	Work Breakdown Structure
WR	Work Rate

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I. INTRODUCTION

Properly managing program cost, schedule, and performance is critical to ensuring that programs meet their intended goals. A program manager is tasked with the responsibility of tracking planned progress versus actual progress to ensure that customers receive value for the time and money expended on programs. The earned value management (EVM) concept is a project management tool that integrates project scope with cost, schedule, and performance elements for optimum project planning and control. The Department of Defense (DoD) Earned Value Management Division states that earned value management should be fully embraced by the DoD acquisition community as an inherent part of the acquisition program management value chain because it provides program managers accurate and timely insight into cost, schedule and performance of DoD weapons systems and services programs (EVM, 2012). Today's shrinking defense budgets focus DoD acquisitions on efficient use of time and money to give the best solution to the warfighter and the taxpayer.

EVM has been used by DoD to forecast program cost and schedule growth over the last four decades. EVM can be defined as a project management technique that focuses on the planned worked accomplished and management's planned budget for the work for the purpose of monitoring performance and predicting the final required costs and the time necessary to finish the project. EVM has been used by DoD since the 1960s as part of the Cost/Schedule Control Systems Criteria (C\SCSC) and more recently in 32 EVMS guidelines for reporting program cost and schedule information. These guidelines have been adopted by the American National Standards Institute/Electronic Industries Alliance (ANSI/EIA-748 EVMS) and are being used by both government and industry. EVM tracks the cost and schedule progress and reports what the program truly earned for the budget that was spent.

EVM is required on all defense acquisition program cost or incentive contracts over $20 million to help program managers track performance and predict potential overruns throughout the acquisition life cycle. In a revision to the DoD earned value management policy memorandum Michael Wynne, former Under Secretary of Defense Acquisition, Technology and Logistics (USD (AT&L), required the implementation of EVM methods and contract performance reports for all cost or incentive contracts valued at or greater than $20 million in then-year dollars and it was incorporated in Department of Defense Instruction (DoDI) 5000.02 (2008).

EVM has been used by acquisition professionals to forecast the program's schedule performance using cost-based indicators but does not completely address time-based indicators. Therefore, even though EVM has been used since the early 1960s as a program estimating tool it is viewed by some professionals as incomplete when predicting schedule performance indicators. An extension of EVM, called earned schedule, was introduced in 2003 as a tool to more accurately estimate schedule performance using EVM performance indicators that were lacking in traditional EVM metrics.

Earned schedule (ES) was developed by Walter H. Lipke and published in the March 2003 edition of the Program Management Institute College of Performance Management Journal (Lipke, 2003). It was developed to provide a unique method to determine schedule performance using the standard EVM performance indicators of budgeted cost of work scheduled (BCWS), actual cost of work performed (ACWP), earned value (EV), and budget at completion (BAC). The earned schedule concept identifies the time at which the amount of earned value (EV) accrued should have been earned and calculates schedule performance in terms of time, not costs.

Earned schedule (ES) uses standard EVM performance indicator values and time-based equations to depict the schedule performance and may help a program manager estimate schedule performance more accurately.

A. RESEARCH SCOPE

This study captures earned value management and earned schedule data on four DoD MDAPs. It compared traditional EVM and ES performance metrics to forecast final program duration.

The data collection included earned value data on four U.S. Army Chemical Materials Agency (CMA) programs. The programs were selected based on their performance measurement baselines and milestone similarities but due to the complexity of reporting period data only a specific portion of the data was selected for this research project. Specifically, data was collected from the work breakdown structure (WBS), operations phase, after each program was re-baselined to meet a Congressionally mandated April 2012 completion date. After program re-baseline, there were no further schedule changes to the performance measurement baseline (PMB) for the operations phase. Each program had operations phases that began on June 2007 and completed the incineration or neutralization of the chemical stockpile within a five-year period. The similarities between the operations phase, WBS and schedule requirements facilitated correlations between data analysis and conclusions across the programs.

The PMB is highly important to earned value management because it provides the baseline plan to measure the program's performance. It is the sum of the program's planned cost over time and establishes the scope, schedule, and budget for a program. The earned value management implementation guide (EVMIG) describes a baseline as having the following characteristics: it accurately represents only authorized work on the contract, it includes a realistic network schedule baseline, and it includes a realistic time phased spread of budget/resources to the baselined schedule. Additionally, management makes a consistent commitment to enforce proper baseline change procedures and periodically review the remaining baseline to ensure that it remains executable (2006). A consistent schedule lent itself to comparable data between programs and was essential to answering the primary research question.

B. RESEARCH OBJECTIVE

The objective of this research project was to measure the accuracy of EVM and ES final duration forecast metrics on U.S. Army CMA programs. The traditional EVM method of estimating schedule performance uses cost-based indicators and Integrated Master Schedule (IMS) (DoDI 5000.02, 2008) to represent time. But, the research will not examine the DoD EVM practice of using the IMS to estimate program schedule. The research will only use derived mathematical equations to measure schedule performance metrics from EV data.

The research will determine if the earned schedule method for final duration forecast produces a more accurate measure of the program's final duration. The research paper will answer the following questions:

1. Primary Research Question

Is the ES method for the final duration forecast more accurate than EVM methods for final duration forecast for U.S. Army CMA programs?

2. Secondary Research Questions

a) How do EV and ES final duration forecast values compare?

b) Can the ES final duration forecast be easily applied to DoD MDAPs?

C. METHODOLOGY

The research project methodology was developed to show the comparative value of EVM and ES final duration forecast methods to DoD programs. It collected traditional earned value management indicator data on four similar U.S. Army CMA programs and measured final duration forecast values for EVM and ES methods. The study used statistical analysis on the forecast values to determine the variation from the actual final duration over time and, thus, the accuracy of the methods.

EVM data was collected on four U.S. Army CMA programs for work reported from October 2007 until the completion of the operations phase (munitions destruction). The earned value and planned value cost-based data was used to calculate EVM and ES performance metrics and produced forecasts for final program duration.

A spreadsheet was used to calculate all necessary data for the research study. An ES spreadsheet for partial time periods was used as the basis for the data analysis and subsequently modified to include final duration forecast, mean squared error, and percent difference values.

Final duration forecasts were determined using two EVM methods and one ES method. The three methods were the EVM planned value and earned value methods, and the earned schedule method. Respective forecasts for each reporting period, Mean Squared Error (MSE), and percent differences were calculated for each method.

The mean squared error was selected because it reduced all forecast values to data that could be easily analyzed to answer the primary research question. It showed the statistical variation of the forecasted final duration about the actual duration value and was used to measure forecast method accuracy.

This research project calculated MSE at program percent complete periods to measure the sensitivity of the methods to time. MSE was ranked over early (10–40 percent), mid (40–70 percent), and late (70–100 percent) stages for each program. Smaller MSE values showed less spread in the data and therefore, forecasted values that were nearer to the actual final duration.

This research project also used percent difference calculations to measure the accuracy of the final forecast value compared to the actual value over time. Percent difference values closer to zero represented forecasted values that were nearer to the actual final duration.

D. ORGANIZATION

This research paper is organized to allow for a logical progression from objective to conclusion and answering the primary research question: Is the ES method for the final duration forecast more accurate than EVM methods for final duration forecast for U.S. Army CMA programs?

The INTRODUCTION chapter gives an expanded version of the research proposal. It establishes the scope, objective, and methodology of the research paper.

The BACKGROUND chapter introduces the concepts of earned value management and earned schedule. It specifically addresses the key schedule performance metrics and applies them to the final duration forecasts.

The CASE STUDY AND ANALYSIS chapter examines four U.S. Army CMA programs using earned value indicators over consistent schedule baselines. It documents the traditional EVM and ES forecasted final duration methods to measure their accuracy as predictors. An accuracy comparison is drawn between the methods to help answer the primary and secondary research questions.

The SUMMARY AND RECOMMENDATIONS chapter provides the answer to the primary research question.

II. BACKGROUND

A. EARNED VALUE MANAGEMENT CONCEPT

In a memorandum for acquisition professionals, The Honorable Dr. Ashton Carter (former USD (AT&L)) emphasized the need to deliver better value to the taxpayer and warfighter by improving the way the Department of Defense does business.

> We must therefore abandon inefficient practices accumulated in a period of budget growth and learn to manage defense dollars in a manner this is, to quote Secretary Gates at his May 8, 2010 speech at the Eisenhower Library, "respectful of the American taxpayer at a time of economic and fiscal distress." (Carter, 2010)

As a means to achieve better value, cost and schedule metrics that track forecasted performance became key DoD program management tools. Earned value management is one such tool.

Earned value management is a widely accepted practice for project management that is being used across the DoD, the Federal government, and industry. It is an integrated management system that coordinates the work scope, schedule, and cost goals of a program or contract, and objectively measures progress toward these goals. EVM provides a prediction of the final costs and schedule requirements and is used by program managers to:

- quantify and measure program/contract performance
- provide an early warning system for deviation from a baseline
- identify and track risks associated with cost and schedule overruns
- provide a means to forecast final cost and schedule outcomes

Earned value simply allows the project manager to take advantage of their actual results and forecast the final results. If corrective actions are taken on overruns during the early stage of the program the program manager may change the forecasted outcome. EVM provides the program manager a powerful tool in the successful cost and schedule completion of a program.

EVM uses performance indicators and metrics to objectively measure program progress against the budgeted plan. The performance indicators provide the input to measure the key schedule performance metrics used in EVM analysis. But, by themselves, earned value data indicators are not adequate to manage the project's time dimension (Fleming & Koppelman, 2010).

1. Performance Indicators

Figure 1 shows notional data for a program with key EVM indicators plotted, namely, BCWS, ACWP, EV, and BAC. The EVM indicators are defined as follows:

- BCWS, also called planned value (PV), is the ideal time-phased budget program plan for work currently scheduled or, more specifically, how much work the program should have accomplished at a specific time and cost.
- ACWP is the actual cost incurred while accomplishing the program work. The ACWP value may be higher or lower than the BCWP at a specific time increment depending on the program's progress.
- EV is the budgeted cost for work performed (BCWP) on a program. It is the value of the completed work in terms of the work's assigned budget, not simply what has been spent on the program.
- BAC is budgeted cost at completion.

A monthly contract performance report (CPR) is submitted to the government program manager with detailed performance indicator data (Data Item Description (DID) DI-MGMT-81466A, 2005) to monitor and measure EVM metrics.

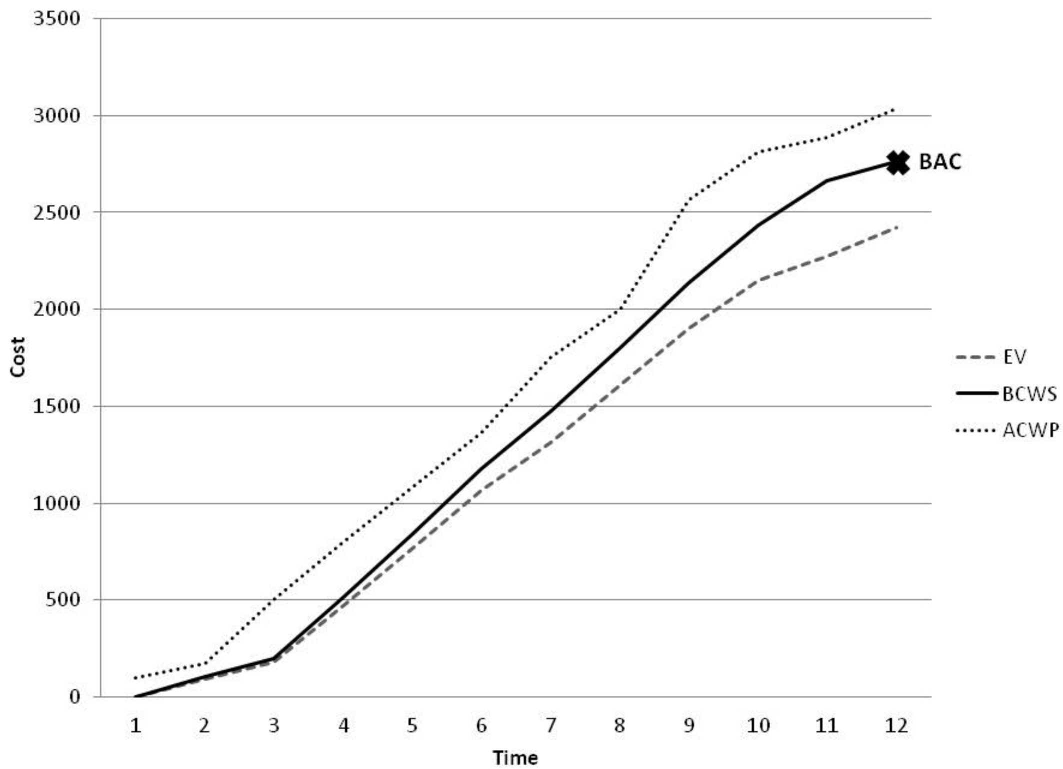

Figure 1. EVM Indicators

2. Schedule Performance Index

An important schedule metric that can be derived from the EVM indicators is the program's schedule performance index. The SPI helps predict the duration of the planned work by determining if the project is ahead, on, or behind schedule at any point in time on the BCWS line. It is calculated with cost-based data and can be an early indicator of program schedule problems. It is a measure of the program's schedule efficiency and is calculated by taking the ratio of the earned value to the BCWS. The following equation was used to calculate SPI:

$$SPI = \frac{EV}{BCWS} \ .$$

The ratio yields a larger value when more work was performed than the planned value. Conversely, the ratio yields a smaller value when less work was performed than the planned value. Favorable, or schedule efficient programs have a SPI value greater than 1.0 and inefficient programs have a SPI value less than 1.0.

Figure 2 shows notional SPI data for a program that completed behind schedule. The data represents a program that was scheduled for a 12-month completion date, but finished in 15 months. It shows baseline and actual SPI values plotted on the graph. Baseline SPI values show an ideal value throughout the program's planned schedule and the SPI line shows the program's actual schedule efficiency. The program's SPI values fluctuate depending on the amount of planned work budgeted compared to the earned value of the work.

The Figure 2 program had poor schedule performance and indicated that the program may not complete within the 12-month planned schedule. The SPI values were less than 1.0 until program completion and did not start to improve until month 10. At 12 months, the program had not completed as planned but continued to improve until it completed at month 15.

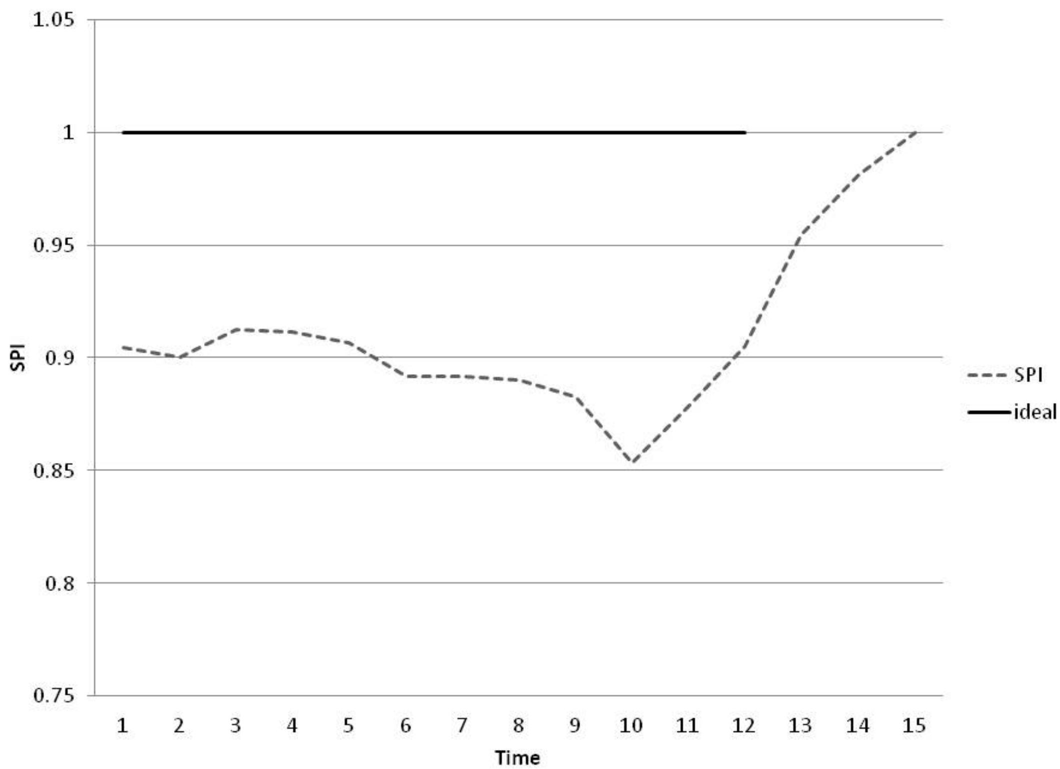

Figure 2. SPI for Late Completing Program

Using traditional earned value management methods, actual SPI values will naturally reach an ideal value of 1.0 at program completion because SPI values are calculated with costs. EVM calculates schedule efficiency based on budgeted costs and therefore may not accurately reflect time-base schedule efficiency. At program completion all funds are expended and the SPI ratio always equals 1.0. Based on costs, at program completion all programs whether early, on time, or late, show a favorable schedule performance. Program managers must analyze the SPI trend and not just focus on the later program stage values because they may give unreliable indications of schedule performance when assessing risks and corrective actions.

3. Final Duration Forecast

Another important metric related to schedule performance that can be derived from the EVM indicators is the independent estimate at completion (IEAC(t)) (Lipke, 2009a). It predicts the program completion time based on elapsed time and forecast of work remaining on the program. The commonly applied form for IEAC(t) equals the elapsed time plus the forecast for work remaining. It can be expressed as the following formula:

$$IEAC(t) = AT + \frac{BAC - EV}{WR}$$

where

AT = actual time when PV and EV are reported

WR = work rate factor that converts work into time.

The two common work rates that are applied to forecast final duration are average BCWS ($BCWS_{av}$) and average earned value (EV_{av}). $BCWS_{av}$ value is used to depict program performance that is expected to progress according to plan. EV_{av} is used to depict program performance that is expected to follow the current SPI trend. The two work rates are shown in the following equations and were used to calculate the $IEAC(t)_{BCWS}$ and $IEAC(t)_{EV}$ values:

$$BCWS_{av} = \frac{BCWS_{cum}}{n}$$

$$EV_{av} = \frac{EV_{cum}}{n}$$

where

$BCWS_{cum}$ = cumulative value of BCWS

EV_{cum} = cumulative value of EV

n = total number of time increments within AT.

EVM methods for forecasting project duration have been taught in training courses and used by project managers for four decades (Lipke, 2009a). But, EVM cost-based indicator values may not always accurately predict time. So, the earned schedule method was developed to measure schedule performance using standard EVM indicators and time.

B. EARNED SCHEDULE CONCEPT

In March 2003, Walter Lipke published a paper in The Measurable News that introduced an extension of earned value management that tracked program schedule in units of time rather than traditional EVM units of budget, called earned schedule (Lipke, 2003). It was developed in response to the noted deficiency in using EVM cost-based indicators to effectively evaluate program schedule performance. Schedule performance is important because if a product is not delivered on time there can be serious repercussions. In addition to the likelihood of increased project costs, the customer, internal or external, is deprived of using the product, consequently preventing the delivery of their product or service (Lipke, 2009a).

The basis for the earned schedule concept is straightforward. Identify the time at which the amount of earned value (EV) accrued should have been earned. By determining this time, time-based indicators can be formed to provide schedule variance and performance efficiency management information (Earned Schedule, 2012).

ES also uses performance indicators and metrics to objectively measure program progress against the budgeted plan. The performance indicators provide the input to calculate the key schedule performance metrics used in ES analysis. ES can also provide schedule performance indicators that aide a program manager in the successful completion of a program.

1. Performance Indicators

From the time of the development of EVM indicators, it has been known that the schedule performance metrics are flawed and exhibit strange behavior over the final third of a project, when performance is poor (Lipke, 2003). As a program nears completion, the BCWS and BCWP naturally approach each other so that all scheduled budgets have been used and the program theoretically completed on time using EVM schedule performance metrics. The standard EVM performance indicator data included in the CPR only represents budget data and any schedule metrics calculations from it will not measure time. Therefore, EVM schedule performance metrics have not always been viewed by project mangers as being reliable indicators for schedule (Lipke, 2003).

Figure 3 shows notional data for an acquisition program with EV and BCWS plotted on the graph. The new value, earned schedule, is calculated by projecting the EV data point onto the BCWS curve to determine where EV equals the planned value (BCWS) for the program. Graphically, the horizontal dashed line projection from the EV_t curve to the BCWS curve identifies the time that amount of EV should have been earned in accordance with the schedule. Extending a vertical dashed line from the BCWS curve to the x- axis yields a time increment for the earned schedule value.

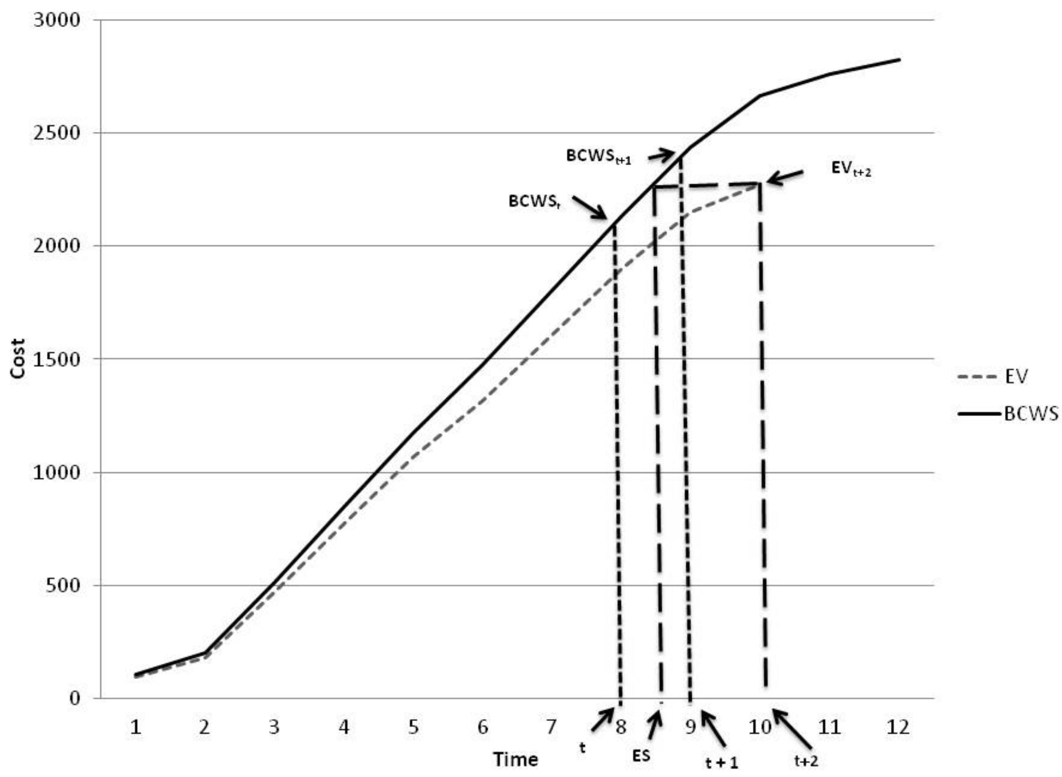

Figure 3. ES Indicators

The earned schedule principle can be graphically explained but an equation is needed to accurately calculate the ES values. The equation uses actual EV and BCWS data values that are supplied in monthly CPRs. The following equation uses linear interpolation to calculate the earned schedule:

$$ES = t + \left(\frac{EV_{t+2} - BCWS_t}{BCWS_{t+1} - BCWS_t} \right).$$

The linear interpolation method that was used to determine ES is represented in Figure 4.

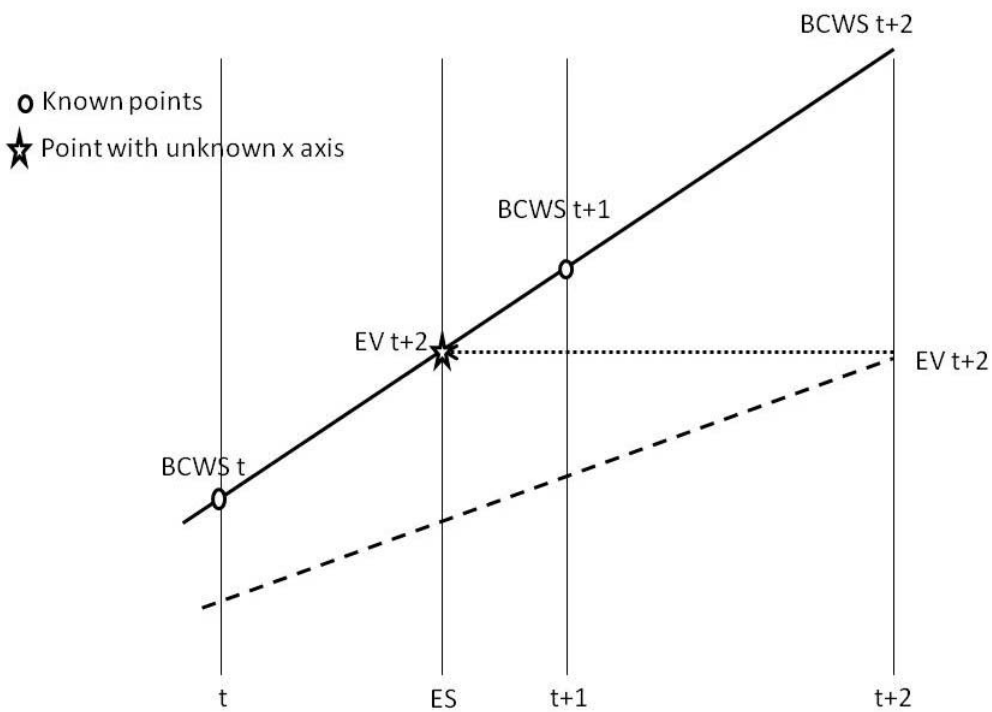

Figure 4. Linear Interpolation Method to Calculate ES (From Fast, 2012)

Using t=8, EV_{t+2}=2300, $BCWS_t$=2135, $BCWS_{t+1}$=2435 from Figure 3 data yields a value of 8.55 months, which indicates that the program was behind schedule because it took 10 months to accomplish work that was only planned for 8.55 months.

$$ES = 8 + \left(\frac{2300 - 2135}{2435 - 2135} \right) = 8.55$$

2. Schedule Performance Index

The important performance metric that can be derived from the ES is the program's schedule performance index, SPI(t). It is a representation of how efficiently a program is performing to schedule. Lipke derived it from the ratio between actual time expended (ATE) and earned schedule. The following equation was used to calculate SPI(t):

$$SPI(t) = \frac{ES}{ATE} \ .$$

Just as in traditional EVM schedule performance metrics, an SPI(t) value greater than 1.0 is favorable and a value less than 1.0 is unfavorable.

Figure 5 shows the notational SPI(t) data for an acquisition program that completed behind schedule. The data represents a program that was scheduled for a 12-month completion date, but finished in 15 months. Just as in traditional EVM, the baseline SPI values equaled 1.0 throughout the program's planned schedule. But, the actual SPI(t) lines showed different values than the SPI graph from Figure 2. The program performed poorly throughout its' duration and it was clear by the SPI(t) values that the program was in danger of not completing on time. All SPI(t) values are less than 1.0 and after the planned 12-month completion date they did not improve as the program reached completion because the program completed behind schedule. The critical difference between EVM and ES schedule performance index metrics is time.

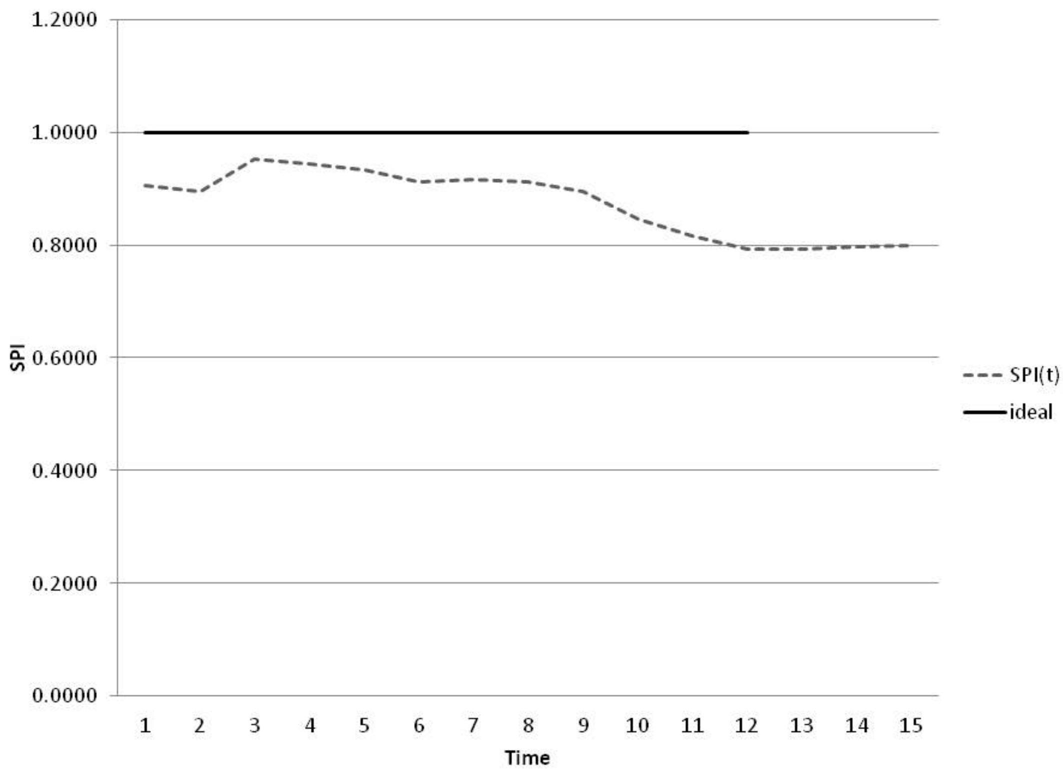

Figure 5. SPI(t) for Late Completing Program

SPI(t) calculations factor in the time that the earned value should have been accomplished and the actual time it was accomplished. Therefore, SPI(t) does not necessarily reach favorable numbers for all programs because costs are not the primary variables. ES metrics yield values that vary depending on the schedule efficiency measured in time.

3. Final Duration Forecast

Just as with EVM, earned schedule performance metrics can also be used to forecast final duration. The major difference between the two methods is that ES incorporates time with the planned duration (PD) and SPI(t) values in the equation. Lipke derived the following equation to calculate ES final duration forecast ($IEAC(t)_{ES}$):

$$IEAC(t)_{ES} = \frac{PD}{SPI(t)} \ .$$

A simulation study published in The Measurable News journal compared EVM and ES duration forecast methods and concluded that the ES metrics outperform, on the average, EVM duration forecast methods. Also, the ES method is more reliable in all stages (early stage, mid stage, late stage) of the project life cycle (Vanhouke, 2007).

C. STATISTICAL ANALYSIS

Statistical methods were used to determine the difference between estimated values (forecasted final duration) and true values (actual final duration) and indicate the accuracy of the forecast. Lipke used the following equation, termed standard deviation, to determine the relative accuracy of the forecasted value about the actual value in his research (Lipke, 2009b):

$$\text{Standard Deviation} = \sqrt{\frac{\sum_i (IEAC(t)_m(i) - FD)^2}{n-1}} \ .$$

Lipke's equation attempted to determine the variance of the forecasted values about the actual value at each time increment. But, a major difference between Lipke's equation and the common standard deviation equation is a mean value. Standard deviation calculates deviation about a mean value and Lipke's equation does not use a mean value, rather, it uses the fixed final duration value. This variation from the common standard deviation equation led the author to examine an alternate statistical equation for this paper.

The author chose the mean squared error equation to measure the variance in the forecasted value about the actual value:

$$MSE = \frac{1}{n}(\sum_{i=1}^{n}(IEAC(t)_i - FD))^2$$

where

$IEAC(t)_i$ = independent estimate at completion for each reporting period

FD = actual final duration

n = number of reporting periods (entire known population).

The MSE and Lipke's standard deviation equation are very similar to each other. Both measure the squared value of the summation of the difference between IEAC(t) and FD divided by a number of time increments. In Lipke's equation, the square root of the summation squared is shown to equal the standard deviation. Statistically, the squared root of the variance equals the standard deviation. The author chose MSE to show the variance in the forecast about the actual value but, taking the square root of MSE yields the root mean square deviation (RMSD), also known as standard deviation. Therefore, the RMSD is analogous to Lipke's standard deviation equation and the author believes that MSE accurately measures the error between the forecasted and actual value while still maintaining the basis of Lipke's research.

A lower MSE indicated that the forecasted duration was closer to the actual duration, whereas a higher MSE indicated that the forecasted duration was further from the actual duration. The goal of this equation is to show an IEAC(t) method that is closest to the actual duration.

The author also used the percent difference equation to determine the difference in the forecasted value versus the actual value and measure forecasted value accuracy. Percent difference was calculated with the following equation:

$$\text{Percent Difference } = \frac{IEAC(t) - FD}{FD} x100 \text{ .}$$

The percent difference value must remain small enough throughout the program as to not negatively affect the schedule because too large a difference would produce a Nunn-McCurdy Act (1983, § 2433) significant schedule breach indication.

Table 1 summarizes the statistical analysis results as applied to the forecasted final duration analysis.

Table 1. Interpretation of Statistical Analysis Values

Mean Squared Error	Percent Difference	IEAC(t) Accuracy
Low	Low	High
High	High	Low

D. SUMMARY OF THE EVM AND ES PERFORMANCE METRICS

The ES method for SPI(t) and final duration forecast showed advantages over the EVM method for SPI and final duration forecast. ES used time indicators in the schedule performance equations, rather than the EVM cost indicators, which may more clearly represent program time against the PMB. ES values were also easily measured with existing EVM performance indicator data and the schedule performance calculations only required known program times or dates. Table 2 shows a comparison between EVM and ES performance equations.

Table 2. Summary of EVM and ES Performance Metric Equations

Method	SPI	IEAC(t)
EVM	$\frac{EV}{BCWS}$	$AT+\frac{(BAC-EV)}{BCWS_{av}}$ $AT+\frac{(BAC-EV)}{EV_{av}}$
ES	$\frac{ES}{ATE}$	$\frac{PD}{SPI(t)}$

III. CASE STUDY AND ANALYSIS

A. INTRODUCTION

In November 1985, Public Law 99-145, Section 1142 (50 United States Code, Section 1521) was introduced and required the safe destruction of the US military chemical weapons stockpile. It directed DoD to dispose of the lethal unitary chemical agents and munitions stored at eight Army installations and required disposal facilities to be cleaned, dismantled, and disposed of according to applicable laws and regulations.

U.S. Army CMA was created to incorporate the former Program Manager for Chemical Demilitarization and portions of the U.S. Army Soldier and Biological Chemical Command into one agency. The agency's headquarters, scientific, communications, and support staff are located at the Edgewood area of the Aberdeen Proving Ground, MD.

The U.S. Army CMA is the world leader in programs to store, treat, and dispose of chemical weapons safely and effectively. The agency developed and used incineration and neutralization technologies to safely store and eliminate chemical weapons at seven stockpile sites while protecting the public, its workers and the environment. The U.S. Army CMA fulfilled its mission and safely destroyed the Nation's aging chemical weapons using incineration and neutralization technologies.

The U.S. Army CMA programs exceeded ten years from initial facility construction to complete facility closure and were funded in excess of $50 million each. The contracts were incentive type so they were required to follow DoD EVM policy in accordance with DoDI 5000.02 (2008).

In a revision to the DoD EVM policy, Michael W. Wynne, former USD (AT&L), required programs valued at or greater than $50 million in then-year dollars follow the thirty-two management guidelines published in ANSI/EIA-748 EVMS, submit a monthly CPR, and a monthly IMS.

The four U.S. Army CMA programs selected for this research followed the DoD EVM policy requirements and provided timely and consistent EVM data to the program manager. The programs were selected for this research paper based on their common EVM data, WBS, and schedule characteristics. Specifically, data was collected from the WBS level for the operations phase (agent destruction) after each program was re-baselined to meet a Congress mandated April 2012 completion date. The operations were conducted in the same operations phase WBS level for each program.

Each program had a single prime contractor that managed its validated EVMS with one or two subcontractors that provided EVM data to the prime contractor. The subcontractors were fully integrated into prime contractor so there was only one EVMS per program.

Each program was re-baselined and it was a significant event. The prime contractors were offered large guaranteed monetary incentives to complete the operations phase within schedule. After the program re-baseline on June 30, 2007 there were no further changes to the schedule baseline for the operations phase and each was expected to complete by April 30, 2012. All four U.S. Army CMA programs had the same start date and same planned completion date, which facilitated correlations between data analysis and conclusions across the programs.

Due to the sensitivity of the data no actual program names or contractors will be discussed in this research paper. The programs will be designated Program A, Program B, Program C, and Program D and all data and analysis will be anonymous. Further details on the programs and EV data must be coordinated through the U.S. Army CMA headquarters.

B. PROGRAM A

EVM data was collected for the operation phase (BAC = $207,289,000) over the reporting period 30 June 2007 to 30 September 2011 and used to measure schedule performance metrics.

Figure 6 shows the MSE of the forecasted final duration for the three different IEAC(t) methods. The MSE for each of the IEAC(t) methods converged near the actual duration throughout the program and are consistent with any type of forecast method.

The ES MSE plot was significantly lower than the BCWS and EV plots throughout the program. The ES MSE plot confirms that the ES method gave a closer final duration forecast than the BCWS and EV methods. But, the plots only show that IEAC(t) ES was better relative to the BCWS and EV methods and does not indicate the true accuracy of the data. For example, during the early program stage the MSE values were at least 110 months squared for every reporting period. A MSE =110 translated into a deviation of at least 10 months from the actual duration.

The percent of total program duration was calculated by dividing the forecasted deviation months with the total program duration months. The calculated value gave a clear indication of the relative accuracy of the forecasted value compared to the actual length (time) of the program. In the case of Program A, the forecasted value deviation was 20 percent of the actual program duration, which would not have been useful to a program manager for schedule planning because it would have signaled a false significant schedule breach indicator. Though lower than EV and BCWS methods, the IEAC(t) ES method would still not be helpful to a program manager because it showed Nunn-McCurdy breach indicators that were false.

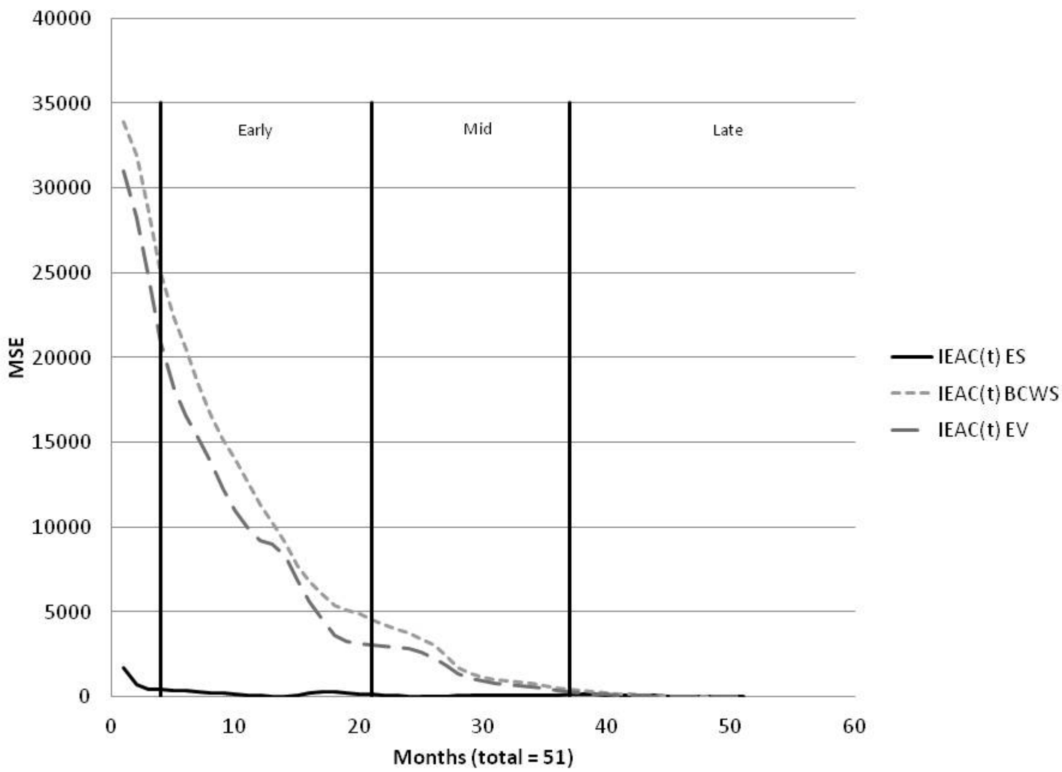

Figure 6. Mean Squared Error Results for Final Duration Forecast–Program A

Figure 7 shows the percent difference of the forecasted duration (IEAC(t)) from the actual duration for each of the three methods plotted over time. Again, all three methods converged near the actual final duration as time progresses because the closer the program gets to completion the more confidence the method had in predicting the actual duration. But, none of the IEAC(t) methods showed a high confidence in helping the program manager forecast events. All IEAC(t) method values were at least 25 percent over the actual duration throughout the majority of the program. Specifically, forecast methods at 25 percent different from the actual duration translate into missing the end date by at least 13 months. That type of inaccuracy in the forecast values would immediately lead to a Nunn-McCurdy Act schedule breach indicator. But, history shows that after program re-baseline the program did not experience a breach and completed ahead of schedule. The data showed that acceptable values, less than 11 percent difference to prevent a Nunn-McCurdy breach indicator, were generally not achieved until the very late stages of the program where it is easier to make accurate forecasts. Though ES IEAC(t) showed improvement over the BCWS and EV IEAC(t) methods it would still not give a program manager confidence in forecasting schedule performance.

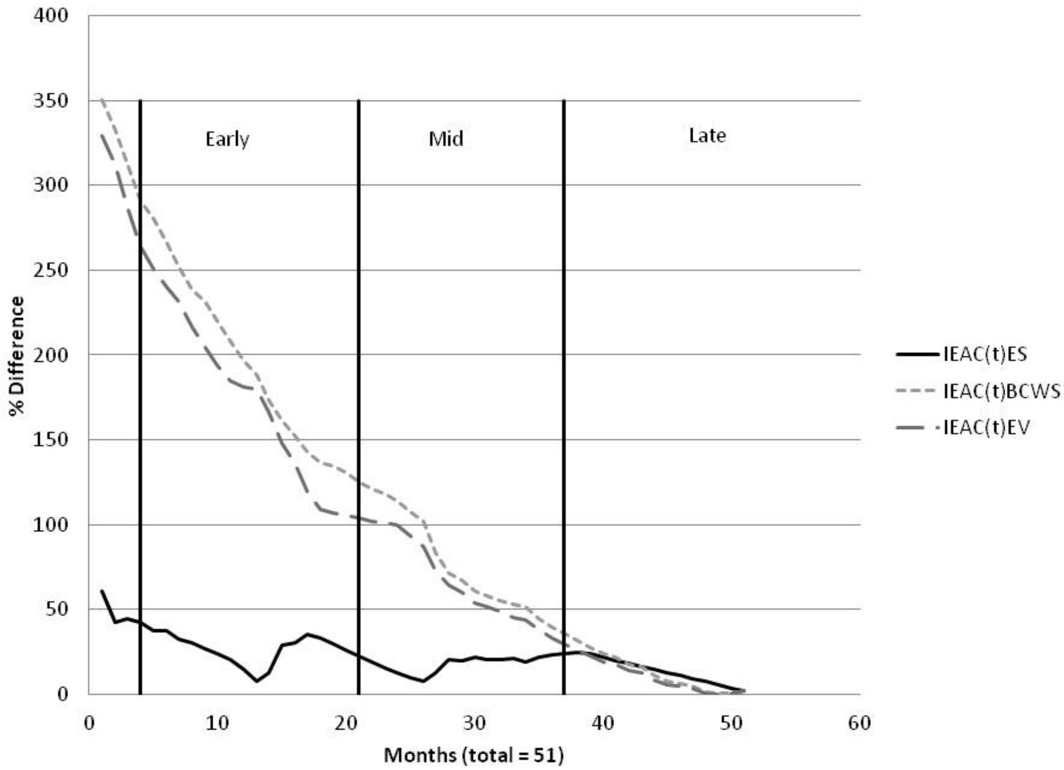

Figure 7. Percent Difference Results for Final Duration Forecast–Program A

C. PROGRAM B

EVM data was collected for the operation phase (BAC = $377,521,000) over the reporting period 30 June 2007 to 29 January 2012 and used to measure schedule performance metrics.

Figure 8 shows the MSE of the forecasted final duration for the three different IEAC(t) methods. The MSE for each of the IEAC(t) methods converged near the actual duration throughout the program and are consistent with any type of forecast method.

The ES MSE plot was significantly lower than the BCWS and EV plots throughout the early and mid program stages. The ES MSE plot confirms that the ES method gave a closer final duration forecast than the BCWS and EV methods. But, the plots only show that IEAC(t) ES was better relative to the BCWS and EV methods and does not indicate the true accuracy of the data. For example, during the early program stage the MSE values were at least 60 months squared for every reporting period. A MSE =60 translated into a deviation of at least 8 months from the actual duration. In the case of Program B, the forecasted value deviation was 15 percent of the actual program duration, which would not have been useful to a program manager for schedule planning because it would have signaled a false significant schedule breach indicator. Though lower than EV and BCWS methods, the IEAC(t) ES method would still not be helpful to a program manager because it showed Nunn-McCurdy breach indicators that were false.

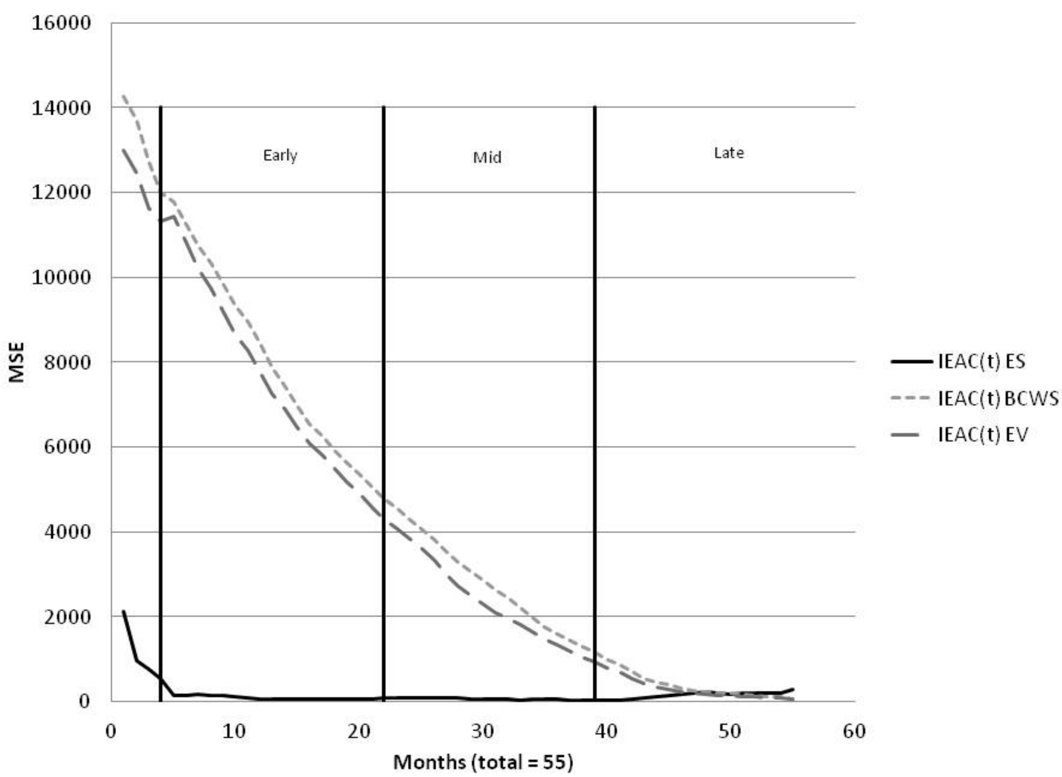

Figure 8. Mean Squared Error Results for Final Duration Forecast–Program B

Figure 9 shows the percent difference of the forecasted duration (IEAC(t)) from the actual duration for each of the three methods plotted over time. None of the IEAC(t) methods showed a high confidence in helping the program manager forecast events. All IEAC(t) method values were at least 15 percent over the actual duration throughout the majority of the program. Specifically, forecast methods at 15 percent different from the actual duration translate into missing the end date by at least 9 months. That type of inaccuracy in the forecast values would immediately lead to a Nunn-McCurdy Act schedule breach indicator. But, history shows that after program re-baseline the program did not experience a breach and completed ahead of schedule. The data showed that acceptable values, less than 10 percent difference, to prevent a Nunn-McCurdy breach indicator were generally not achieved until the very late stages of the program where it is easier to make accurate forecasts. Though ES IEAC(t) showed improvement over the BCWS and EV IEAC(t) methods would still not give a program manager confidence in forecasting schedule performance.

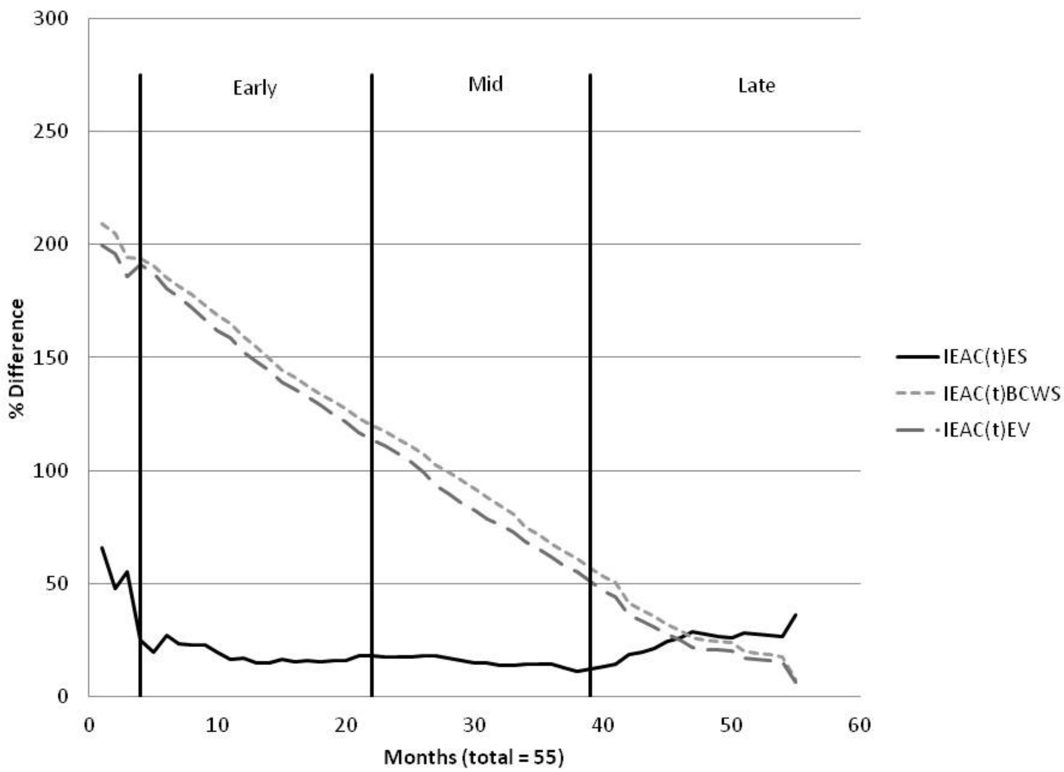

Figure 9. Percent Difference Results for Final Duration Forecast–Program B

D. PROGRAM C

EVM data was collected for the operation phase (BAC = $175,112,000) over the reporting period 30 June 2007 to 28 October 2011 and used to measure schedule performance metrics.

Figure 10 shows the MSE of the forecasted final duration for the three different IEAC(t) methods. The MSE for each of the IEAC(t) methods converged near the actual duration throughout the program and are consistent with any type of forecast method.

The ES MSE plot was significantly lower than the BCWS and EV plots throughout the program. The ES MSE plot confirms that the ES method gave a closer final duration forecast than the BCWS and EV methods. But, the plots only show that IEAC(t) ES was better relative to the BCWS and EV methods and does not indicate the true accuracy of the data. For example, during the early program stage the MSE values were at least 57 months squared for every reporting period. A MSE =57 translated into a deviation of at least 8 months from the actual duration. In the case of Program C, the forecasted value deviation was 15 percent of the actual program duration, which would not have been useful to a program manager for schedule planning because it would have signaled a false significant schedule breach indicator. Though lower than EV and BCWS methods, the IEAC(t) ES method would still not be helpful to a program manager because it showed Nunn-McCurdy breach indicators that were false.

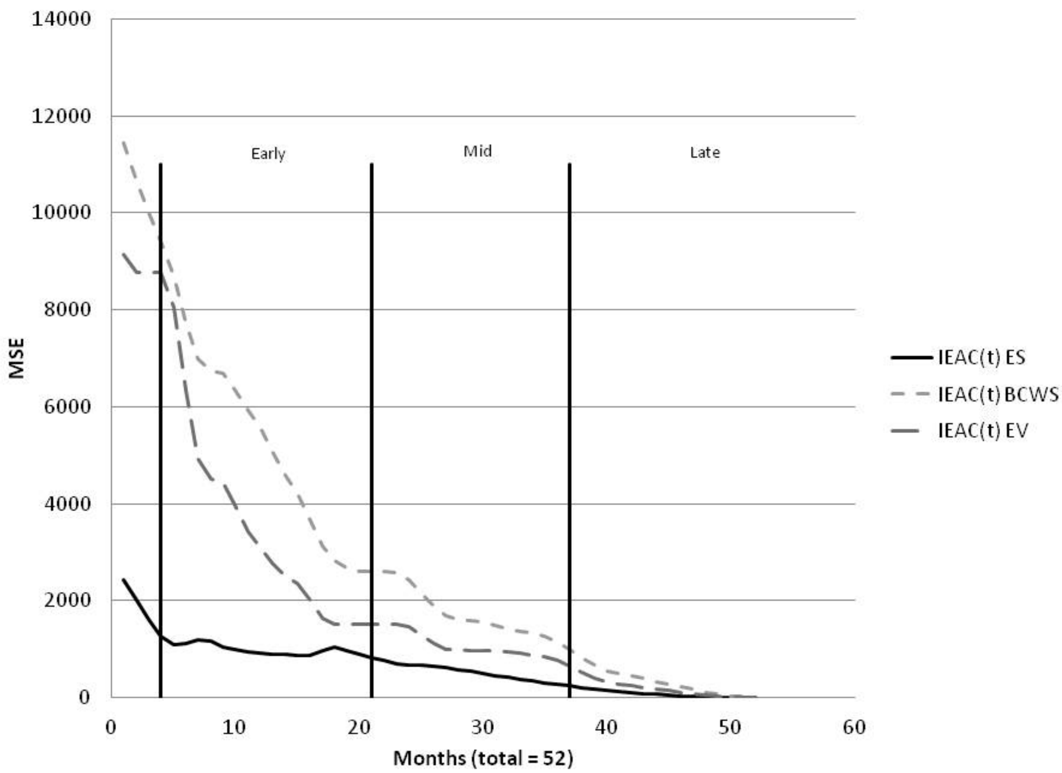

Figure 10. Mean Squared Error Results for Final Duration Forecast–Program C

Figure 11 shows the percent difference of the forecasted duration (IEAC(t)) from the actual duration for each of the three methods plotted over time. Again, all three methods converged near the actual final duration as time progresses because the closer the program gets to completion the more confidence the method had in predicting the actual duration. But, none of the IEAC(t) methods showed a high confidence in helping the program manager forecast events. All IEAC(t) method values were at least 30 percent over the actual duration throughout the majority of the program. Specifically, forecast methods at 30 percent different from the actual duration translate into missing the end date by at least 16 months. That type of inaccuracy in the forecast values would immediately lead to a Nunn-McCurdy Act schedule breach indicator. But, history shows that after program re-baseline the program did not experience a breach and completed ahead of schedule. The data showed that acceptable values, less than 11 percent difference, to prevent a Nunn-McCurdy breach indicator were generally not achieved until the very late stages of the program where it is easier to make accurate forecasts. Though ES IEAC(t) showed improvement over the BCWS and EV IEAC(t) methods would still not give a program manager confidence in forecasting schedule performance.

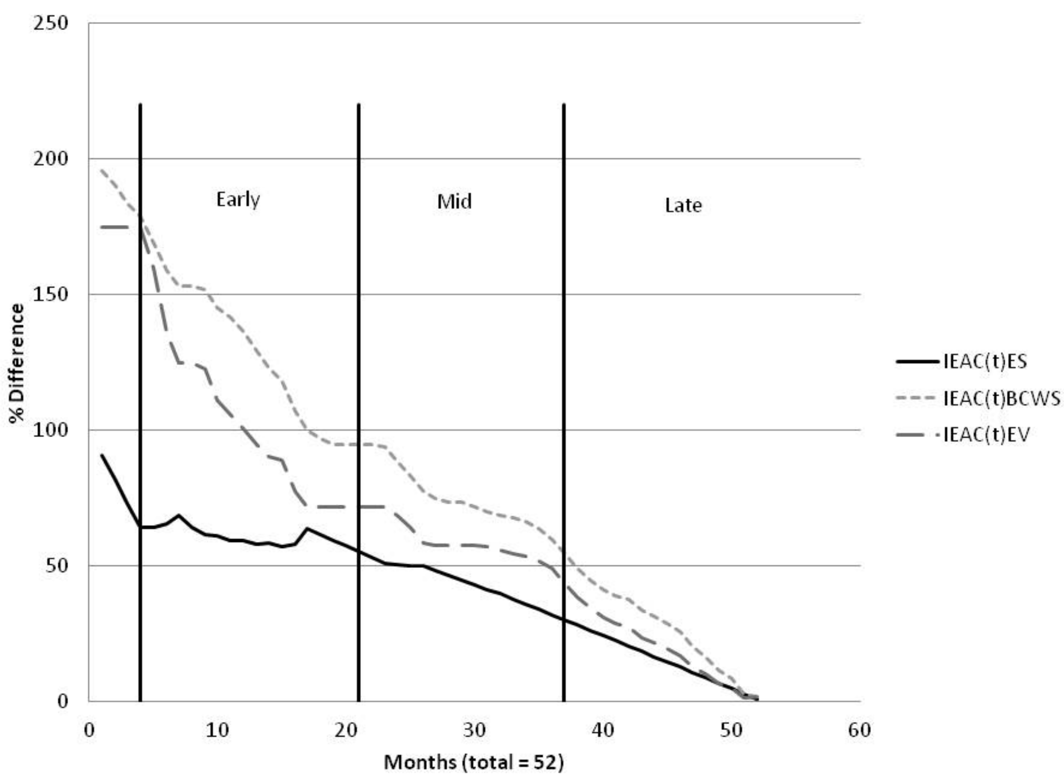

Figure 11. Percent Difference Results for Final Duration Forecast–Program C

E. PROGRAM D

EVM data was collected for the operation phase (BAC = $113,232,000) over the reporting period 30 June 2007 to 26 November 2010 and used to measure schedule performance metrics.

Figure 12 shows the MSE of the forecasted final duration for the three different IEAC(t) methods. The MSE for each of the IEAC(t) methods converged near the actual duration throughout the program and are consistent with any type of forecast method.

The ES MSE plot was significantly lower than the BCWS and EV plots throughout the program. The ES MSE plot confirms that the ES method gave a closer final duration forecast than the BCWS and EV methods. But, the plots only show that IEAC(t) ES was better relative to the BCWS and EV methods and does not indicate the true accuracy of the data. For example, during the early program stage, the MSE values were at least 119 months squared for every reporting period. A MSE =119 translated into a deviation of at least 10 months from the actual duration. In the case of Program D, the forecasted value deviation was 24 percent of the actual program duration, which would not have been useful to a program manager for schedule planning because it would have signaled a false significant schedule breach indicator. Though lower than EV and BCWS methods, the IEAC(t) ES method would still not be helpful to a program manager because it showed Nunn-McCurdy breach indicators that were false.

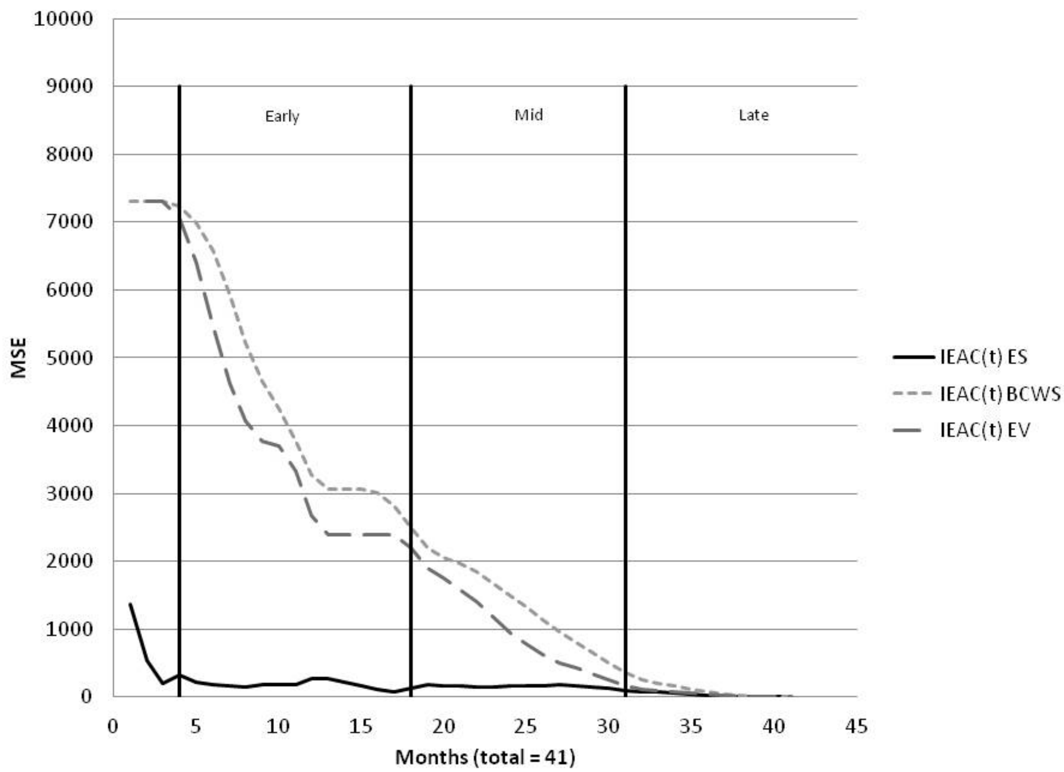

Figure 12. Mean Squared Error Results for Final Duration Forecast–Program D

Figure 13 shows the percent difference of the forecasted duration (IEAC(t)) from the actual duration for each of the three methods plotted over time. None of the IEAC(t) methods showed a high confidence in helping the program manager forecast events. All IEAC(t) method values were at least 30 percent over the actual duration throughout the majority of the program. Specifically, forecast methods at 30 percent different from the actual duration translate into missing the end date by at least 12 months. That type of inaccuracy in the forecast values would immediately lead to a Nunn-McCurdy Act schedule breach indicator. History shows that after program re-baseline the program did not experience a breach and completed ahead of schedule. The data showed that acceptable values, less than 14 percent difference, to prevent a Nunn-McCurdy breach indicator were generally not achieved until the very late stages of the program where it is easier to make accurate forecasts. Though ES IEAC(t) showed improvement over the BCWS and EV IEAC(t) methods would still not give a program manager confidence in forecasting schedule performance.

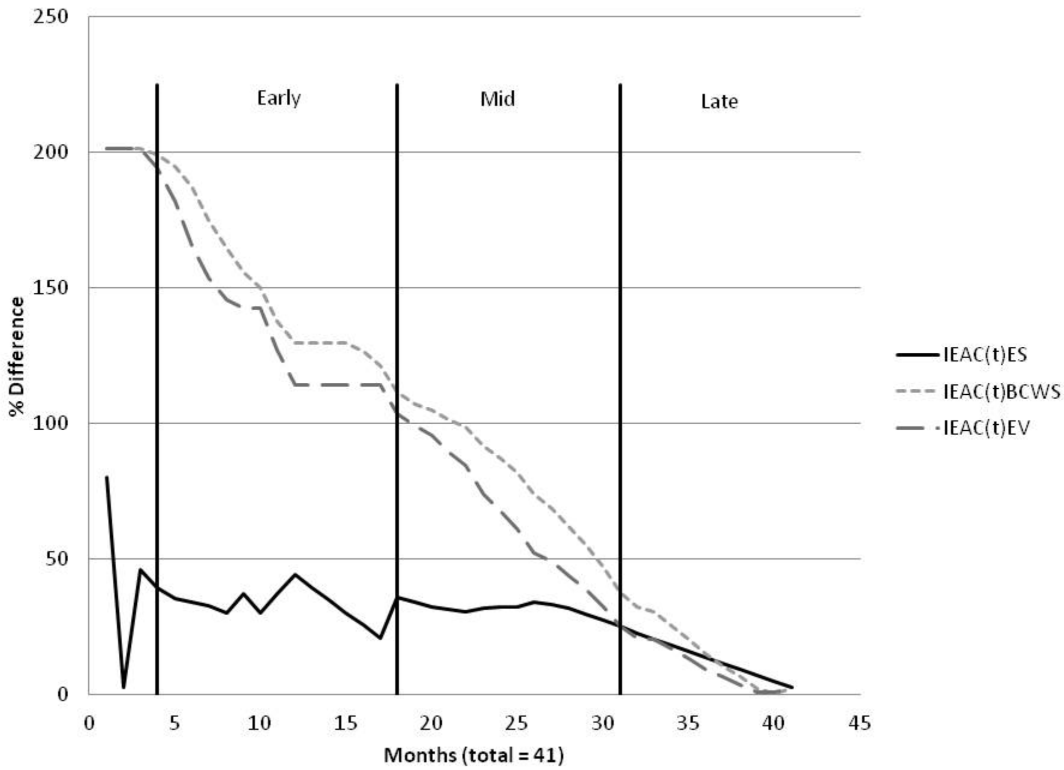

Figure 13. Percent Difference Results for Final Duration Forecast–Program D

F. U.S ARMY CMA CASE ANALYSIS SUMMARY

In summary, analysis of the four U.S. Army CMA programs showed that the ES performance metrics were more accurate indicators of schedule performance than EVM metrics. But, they still did not forecast schedule accurately enough to significantly improve the program manager's ability to effectively manage schedule. Each of the metrics showed IEAC(t) values that exceeded the DoD schedule threshold limits on MDAPs when in reality neither of the programs had a schedule breach during the operations phase. The IEAC(t) methods only showed accurate values during the late stage program stages where forecast values are easier to predict.

Table 3 shows a summary of ES IEAC(t) value accuracy compared to the Nunn-McCurdy Act significant breach threshold.

Table 3. IEAC(t) ES Summary

Program	Total Months	Significant Breach Threshold (months)	Variation about FD			
			MSE		%diff	
			value	months	value	months
A	51	6	110	**<u>10</u>**	25	**<u>13</u>**
B	55	6	60	**<u>8</u>**	15	**<u>9</u>**
C	52	6	57	**<u>8</u>**	30	**<u>16</u>**
D	41	6	119	**<u>10</u>**	30	**<u>12</u>**

IV. SUMMARY AND RECOMMENDATIONS

A. SUMMARY

This Joint Applied Project examined DoD EVM methods to predict schedule performance and final program duration along with the ES method to predict schedule performance and final program duration. This research project applied the schedule performance metrics to four U.S. Army CMA programs to determine if ES metrics were better schedule indicators than EV metrics.

The research showed that the ES metrics were generally more accurate than the EV metrics throughout the program duration. The MSE and percent difference plots of the IEAC(t) compared to the actual duration showed significantly closer forecast values with the $IEAC(t)_{ES}$ method. But, the ES metrics were only more accurate indicators relative to the two EV metrics and did not forecast duration accurately enough to be a useful program management tool. ES metrics predicted false significant schedule breach indicators on each of the four programs, which would have incorrectly caused program stoppage, corrective actions, and potential program cancellation.

The current DoD EVM policy requirement and the familiarity of EVM tools and techniques make the relatively new and unproven ES methods difficult to implement in DoD. But, this research showed that ES performance metrics, specifically the ES value, may have advantages for project management and control that may well prove beneficial for DoD programs. Recommendations are provided below on ways that DoD can use ES methods to improve schedule performance metrics for acquisition programs.

B. RECOMMENDATIONS

1. Recommendation #1

Recommend program managers apply ES performance metrics to complement current EVMS metrics.

The ES metric was a more accurate predictor of schedule duration compared to traditional EV time metrics and it may be valuable to the program manager tool kit. It was easily measured from CPR EVM cost data and can help track schedule performance along with other schedule performance metrics. The author believes that the DoD acquisition workforce is sufficiently trained in EVM principles to effectively use EVM data, measure the ES metric, and skillfully interpret the results.

2. Recommendation #2

Recommend that ES performance metrics for IEAC(t) do not replace current DoD EVMS standards for schedule performance as a program management tool.

ES metrics were not capable of forecasting the final duration within a sufficient level of confidence for a program manager. Each of the four U.S. Army CMA programs showed significant Nunn-McCurdy Act schedule breach indicators based on the IEAC(t) ES data that were false. A program manager using only ES performance metrics would have responded incorrectly to false forecast final duration values.

3. Recommendation #3

Recommend future research on the accuracy of ES performance methods compared to the EVM IMS (DI-MGMT-81650, 2005) and critical path method (CPM) schedule metrics.

CPM is a program scheduling technique that aids in understanding the dependency of events in a program and the time required to complete them. It uses a logic network to predict final project duration by managing those sequences of activities necessary to complete program milestones. IMS is an integrated schedule that details the tasks necessary to ensure program execution. The IMS is traceable to the WBS and is used to measure progress toward meeting program objectives and integrate schedule activities with all related components. Both IMS and CPM were designed to track program schedule performance and a comparative study between them and ES IEAC(t) would show potential differences.

C. CONCLUSIONS

In conclusion, this Joint Applied Project examined DoD EVM equations to predict final program duration and the ES method to predict final program duration. ES schedule performance metrics did not forecast final duration accurately enough to warrant using them as a program management tool for the four U.S. Army CMA programs.

The author believes that some aspects of ES may be a program management tool that should be coupled with EVM methods to more completely integrate project scope with cost, schedule, and performance elements for optimum project planning and control.

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